EBIS Project Overview

Jim Alessi

July 25-27, 2005

Outline of Talk

- Review Agenda
- Scientific/Technical Motivation
- Project History
- Project Performance Objectives
- General layout
- WBS
- Costs & funding
- Schedule
- Deliverables
- Summary

Agenda (day 1)

Monday, July 25, 2005

10:00	Executive Session – Charge	
10:30	Welcome/Introduction	P. Chaudhari, D. Lowenstein
10:45	Project Overview	J. Alessi
11:45	Technical Design, Feasibility (EBIS)	E. Beebe
12:30	Lunch	
13:30	Cost /Schedule/Manpower	K. Mirabella
14:30	Break	
15:00	ESSH	E. Lessard
15:15	Management	J. Alessi
16:00	Executive Session	
18:00	Homework Assignments	
19:00	Dinner	

Agenda (day 2 & 3)

Tuesday, July 26, 2005

08:30	Executive Session	
09:00	Assignment Reports	
09:30	Tour and Break	
10:45	Accelerator and Transport	D. Raparia
11:30	1.1 Structural Components – EBIS, LEBT, external sources	A. Pikin
12:00	1.1 Structural Components – RFQ, Linac, Bunchers	J. Alessi
12:15	Lunch	
13:15	1.4 Magnet Systems	J. Ritter
13:30	1.5 Power Supplies	R. Lambiase
14:00	1.6 RF System	A. Zaltsman
14:15	1.2 Controls	D. Barton
14:30	1.3 Diagnostics System	M. Wilinski
14:45	Break	
15:15	1.7 Vacuum System	M. Mapes
15:30	1.8 Cooling System	R. Grandinetti
15:45	1.9 Facility Modifications	A. Pendzick
16:00	1.10 Installation and Commissioning	L. Snydstrup
16:30	Executive Session	
18:00	Homework Assignments	

Wednesday, July 27, 2005

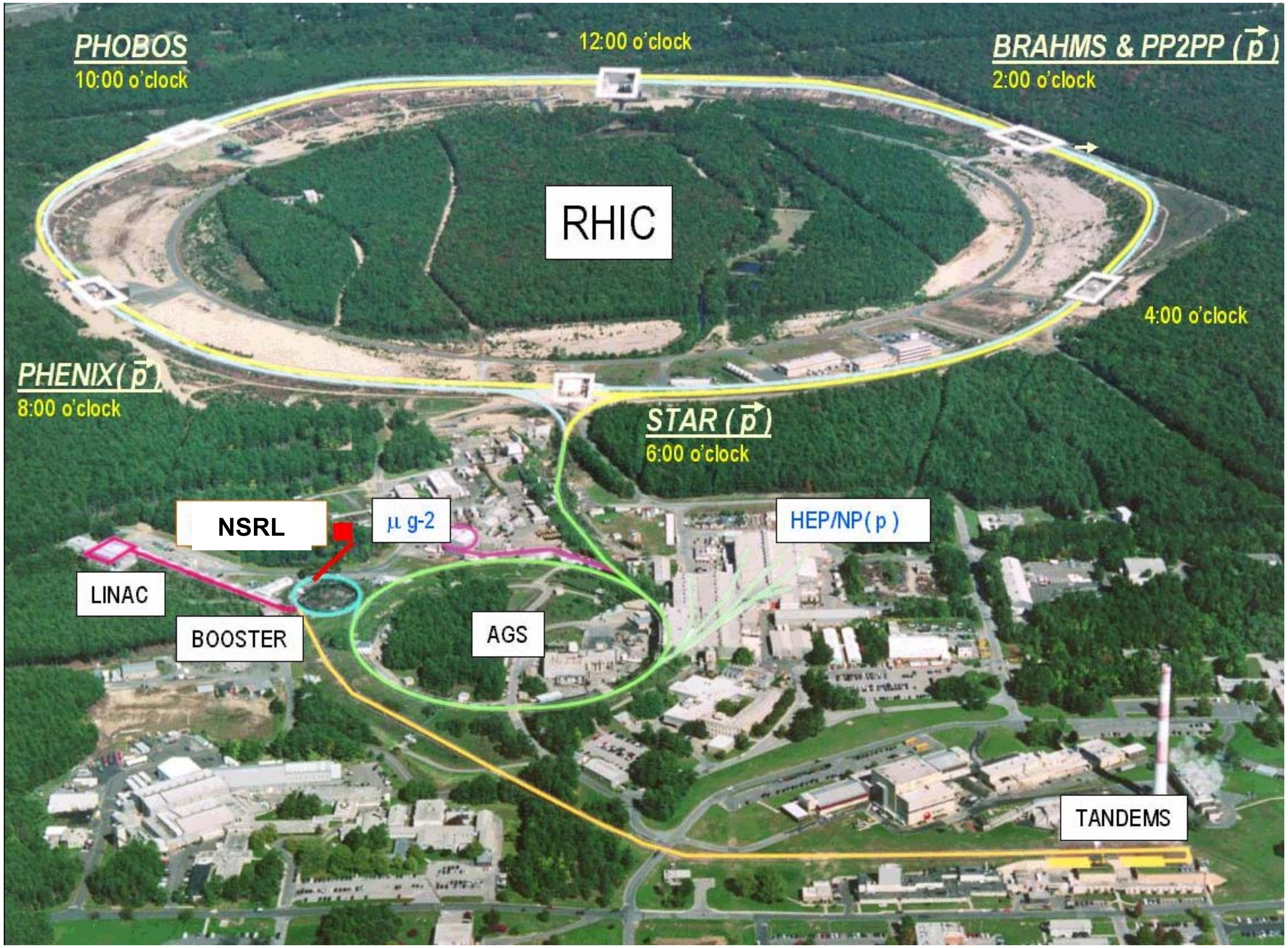
08:30	Assignment Reports
09:30	Report Writing
14:00	Closeout
14:30	Adjourn

Overview

Presently, one or two ~35-year old Tandem Van de Graaff accelerators are used for RHIC pre-injection, but the recent advances in the state of the art in EBIS performance by more than an order of magnitude now make it possible to meet RHIC requirements with a modern linac-based preinjector.

BNL now has DOE CD0 approval for new pre-injector for RHIC based on the Laboratory's development of an advanced Electron Beam Ion Source (EBIS).

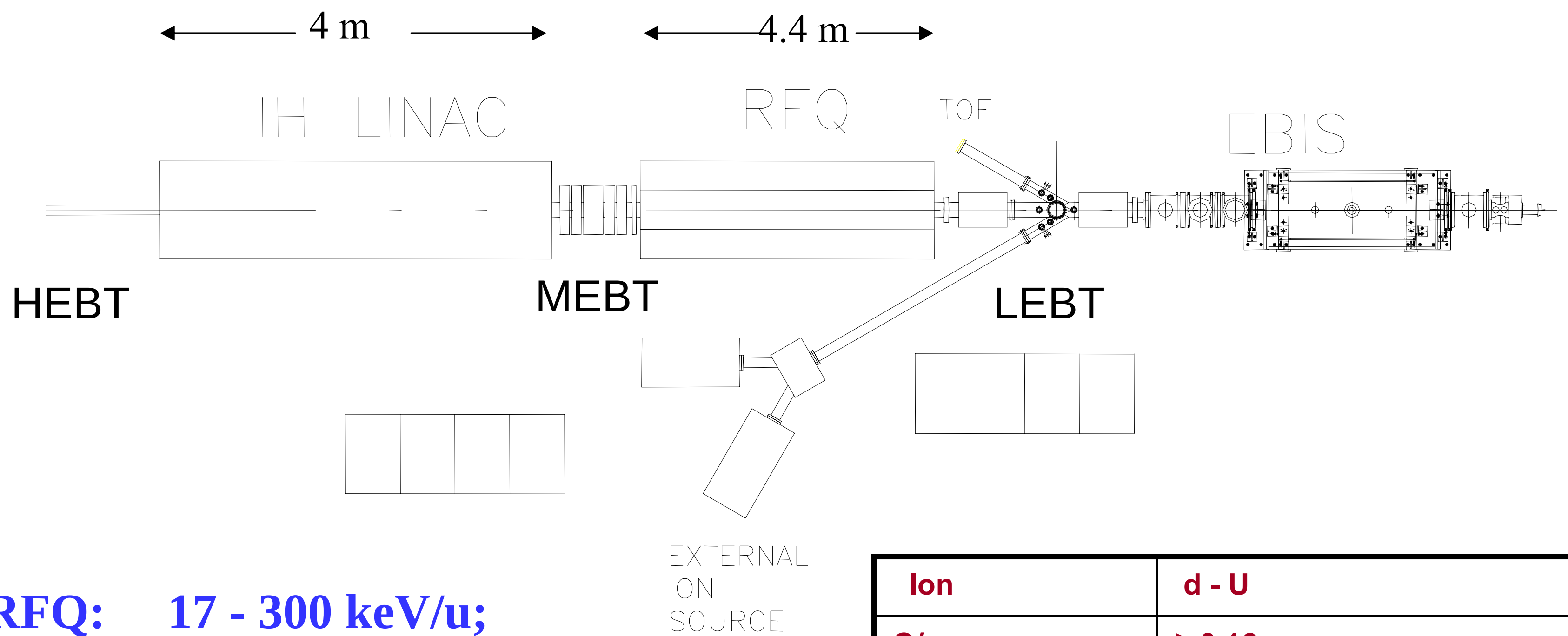
The new preinjector would consist of an EBIS high charge state ion source, a Radio Frequency Quadrupole (RFQ) accelerator, and a short linac.


PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP ($\vec{p}$)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX($\vec{p}$)
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
NSRL
μ g-2
HEP/NP(p)
LINAC
BOOSTER
AGS
TANDEMS

Two Tandems presently serve as RHIC preinjectors

ELECTRON BEAM ION SOURCE

Preinjector Layout



RFQ: 17 - 300 keV/u; 100 MHz

IH Linac: 0.3 - 2.0 MeV/u; 100 MHz

Ion	d - U
Q/m	≥ 0.16
Current	~1.7 emA (for 1 turn inj)
Pulse Length Rep. Rate Duty Factor	10 μs 5 Hz 0.005 %

Scientific/Technical Motivation

- Replacement of the two Tandems as the Booster preinjector, resulting in more stable beam intensities

- Eliminating the need to use the 860-meter long transport line from Tandem to Booster, using instead a much simpler and economic 30-meter long line from EBIS, which will reduce setup time and allow fast switching between beams of different rigidities.

- Simplification of Booster injection scheme (few turn vs. present 40 turn).

- Capability to provide ions not presently available for the NASA program, such as noble gas ions (major components of galactic cosmic rays), as well as more massive ions such as uranium, and with additional enhancements, polarized ^{3}He, for the RHIC program.

Scientific/Technical Motivation (2)

ELECTRON BEAM ION SOURCE

- Increased flexibility to handle the multiple simultaneous needs of RHIC, NSRL and AGS. Two Tandems are needed for fast beam switching, while the EBIS preinjector will be designed to switch between species in 1 second.
- Improvements in reliability, setup time and stability should lead to increased integrated luminosity in RHIC and increased productivity for NSRL.
- Reduced operating costs. The Tandem facility requires a staff of approximately 12 FTEs to support maintenance and a 24-hour shift rotation during operations. The Linac-based pre-injector should be able to run unattended at most times, as with the present proton Linac, and will require only a staff of approximately 3 FTEs.
- If the new EBIS preinjector is not built, ~9 M$ in reliability-driven investments in the Tandems will be required.

Project history

ELECTRON BEAM ION SOURCE

- DOE 2003 RHIC Facility review:
  - "The replacement of the Tandems by an EBIS source has merit and the DOE and BNL are encouraged to implement this."
- BNL 2004 Machine Advisory Committee:
  - "The committee strongly recommends launching the project as soon as possible to replace the present Tandem facility by an EBIS source followed by the RFQ and 2 MeV/u LINAC."
- August, 2004: CD0 Approval – Mission need
- External technical design review – January, 2005.
  - "From the technical point of view the realization of this project is very promising and shows very little risk".
- Internal cost review – February, 2005.
- June, 2005 – SOW between BNL and NASA – contributing 4.5 M$ to the EBIS project.
- Pre-baseline cost range is 15.6 M$ - 19.3 M$ (TPC, AY$).
- Presently 3 year construction, with some NASA-funded long-lead procurements in FY'05, FY'06.

Example, Au injection

ELECTRON BEAM ION SOURCE

Ion	Stage	Energy	Intensity	Transmission	
	EBIS				
Au^{32+}	⇩	17 keV/u	3.4×10^9 ions		(=1e11 charges)
	RFQ			90%	
Au^{32+}	⇩	300 keV/u	3.0×10^9 ions		
	LINAC			90%	
Au^{32+}	⇩	2 MeV/u	2.7×10^9 ions		(=8.6e10 charges)
	BOOSTER			85%	
Au^{32+}	⇩	70 MeV/u	2.3×10^9 ions		
	STRIPPER FOIL			60%	
Au^{77+}	⇩	70 MeV/u	1.4×10^9 ions		
	AGS			90%	
Au^{77+}	⇩	9 GeV/u	1.2×10^9 ions		
	STRIPPER FOIL			100%	
Au^{79+}	⇩	9 GeV/u	1.2×10^9 ions		
	RHIC				

Beams at Booster input

Species	User	Q	Ions/pulse	Charges/pulse
Au	RHIC	32+	2.7×10^{9}	8.6×10^{9}
d	RHIC	1+	2.5×10^{11}	2.5×10^{11}
Cu	RHIC	11+	1.0×10^{10}	1.1×10^{11}
C	NSRL	5+	2×10^{10}	1×10^{11}
O	NSRL	8+	6.7×10^{9}	5.3×10^{10}
Si	NSRL	13+	5×10^{9}	6.5×10^{10}
Ti	NSRL	18+	1.3×10^{9}	2.4×10^{10}
Fe	NSRL	20+	1.7×10^{9}	3.4×10^{10}

These intensities, with the expected 85% efficiency from Booster input to extraction (1-4 turn), will match past runs.

REQUIREMENTS

ELECTRON BEAM ION SOURCE

It is desirable for the preinjector to be able to switch both species and transport line rigidity in ~1 second, so that there are no restrictions on compatibility between RHIC and NSRL operations.

For example:

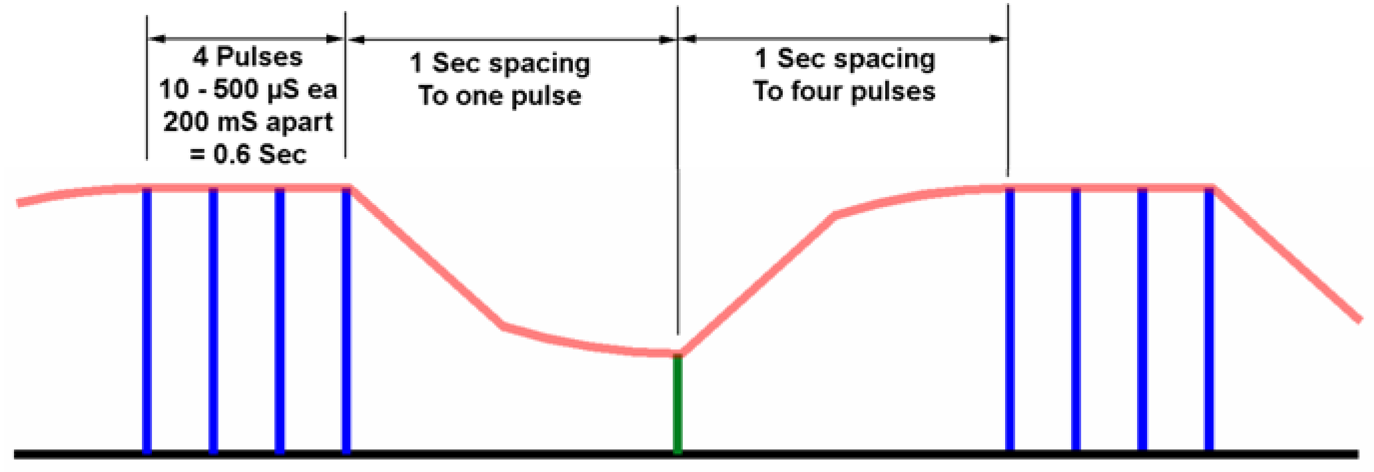
Requirement for RHIC : 1.7 emA of Au^{32+}, 10 µs; 5 Hz

plus….NSRL – *a* second species, 1 second later:

He^{2+}, C^{5+}, O^{8+}, Si^{13+}, Ti^{18+}, Fe^{20+}, Cu^{22+}, at ~2-3 emA, ~ 10 µs

- **short pulses**
- **fast beam changes**
- **any species**

Species switching requirement



The present control system supports "pulse-to-pulse modulation"
The setpoint of any device can be changed pulse-to-pulse, depending on the "user".

So, within 1 second:

- the source (EBIS) has to change species,
- the RFQ and linac have to change gradient (amplitude)
- transport line elements have to switch to new values

Source Options - ECR

ECR

Features, advantages

~ the only choice for high current, high Q, dc applications

Reliable; lots of operating ECRs, lots of experience

Technologies

SC magnets; At high freq's, need SC sol and SC hexapole

28 GHz VENUS - 4 T injection field, 2 T hexapole at plasma chamber

RF power source - 28 GHz gyrotron, 10-15 kW; plus sometimes multiple frequencies

Questions, issues?

Broad charge state distribution, so one has to extract & transport a high total current

Performance depends on species, favoring gases and low melting point solids

“Memory” effects, slow beam switching times at maximum intensities

Source Options – Laser Ion Source

LIS

Features, advantages

Produces high currents, short pulses

Technologies

High power laser – 100 J, CO_2, 15-30 ns
Optics
Targets – 3×10^{13} W/cm^2 on the target

Questions, issues?

Laser reliability, rep rate

Pulse-to-pulse current fluctuations

Target erosion; coating of optics by target material

Species ~ limited to solid targets; high melting point solids are best

Advantages of an EBIS (vs. ECR, LIS)

ELECTRON BEAM ION SOURCE

- An EBIS can produce <u>any</u> type ions – from gas, metals, etc., and is easy to switch species (pulse-to-pulse!)
- One has control over the charge state produced (easy to get intermediate charge states, such as Au^{32+} or U^{45+})
- One has control over pulse width, extracting a fixed charge – can better match to synchrotron requirements
- EBIS produces a narrow charge state distribution (≥ 20% in the desired charge state), so there is less of a space charge problem in the extraction and transport of the total current
- The scaling laws are understood
- The source is reliable, and has excellent pulse-to-pulse stability, long life

Qualitative comparison

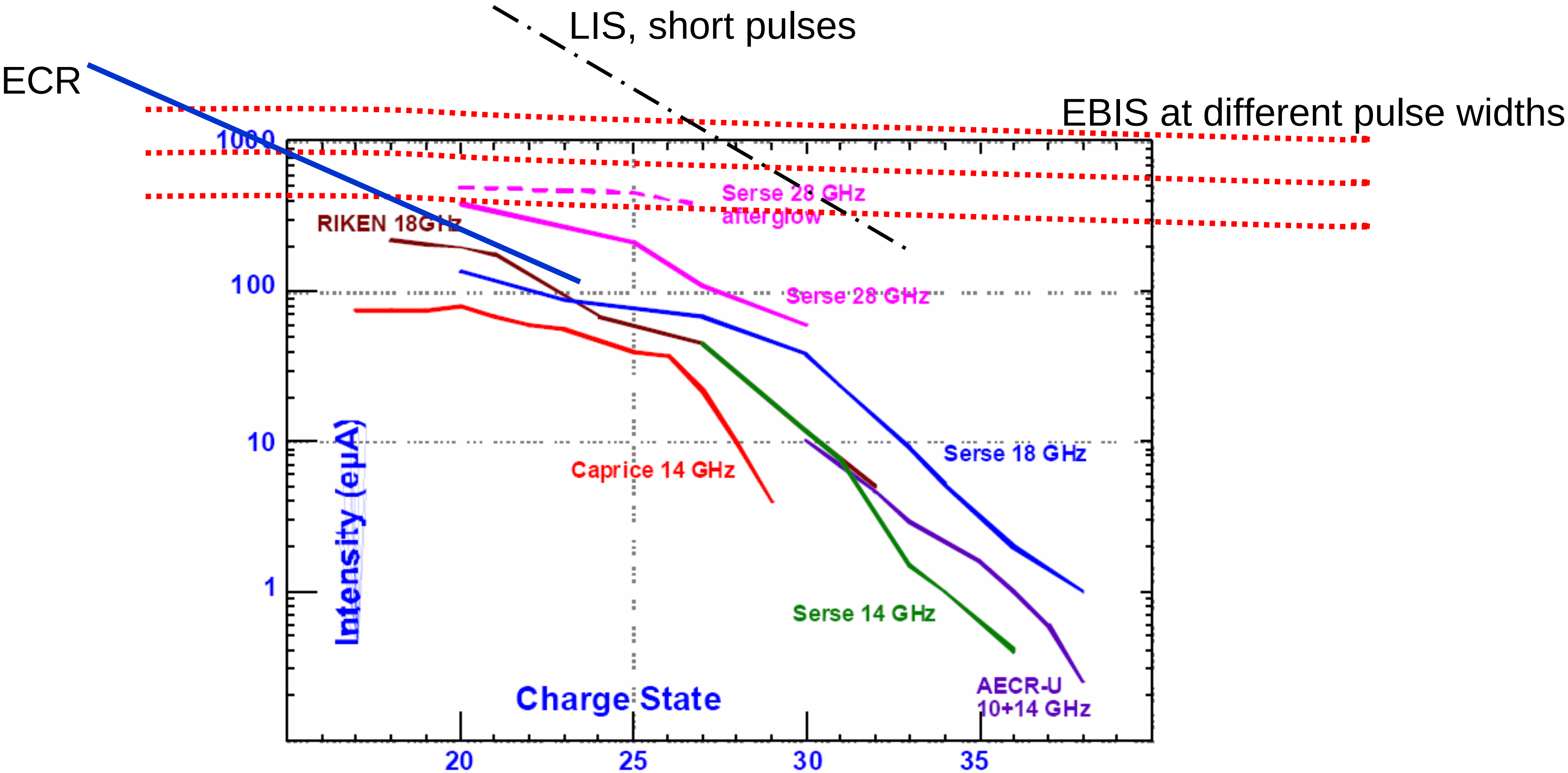
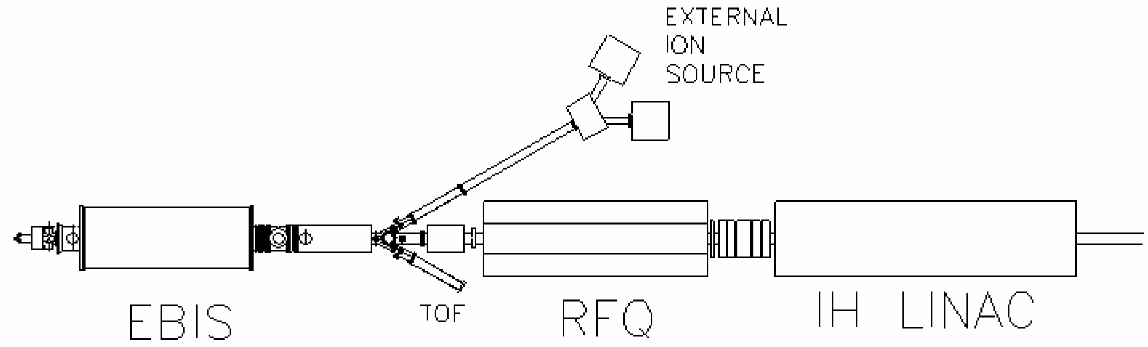


FIG. 14 : Extracted Intensities of Xenon ions for Serse at different frequencies and for other ECRIS.

High-level parameters



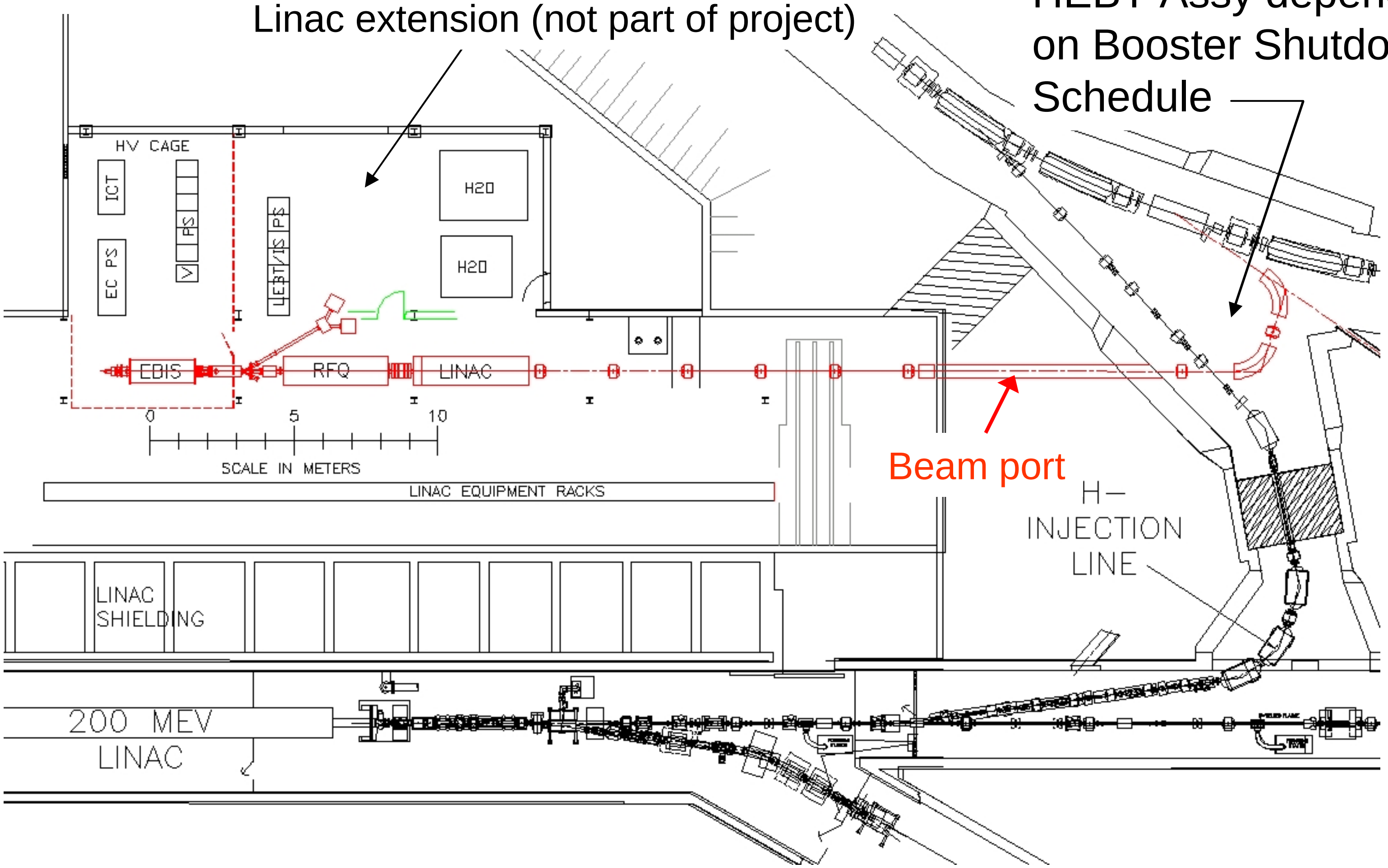
EBIS			
	Output (all charge states)	5×10^{11}	charges/pulse
	Pulse width	10 - 40	μS
	Max rep rate	5	Hz
	Output energy	17	keV/amu
RFQ			
	Q/m	0.16 - 0.5	
	Input energy	17	keV/amu
	Output energy	300	keV/amu
Linac			
	Q/m	0.16 - 0.5	
	Input energy	300	keV/amu
	Output energy	2000	keV/amu
Booster Injection			
	# of turns injected	1-4	

Placement of EBIS Pre-Injector in lower equipment bay of 200 MeV Linac

ELECTRON BEAM ION SOURCE

Linac extension (not part of project)

HEBT Assy dependent on Booster Shutdown Schedule



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July 25-27, 2005

WBS Description

ELECTRON BEAM ION SOURCE

- 1.1 Structural Components
  - Source components, and accelerators; the EBIS hardware, RFQ, Linac, and bunchers
- 1.2 Control Systems
  - All controls for the project. Networked, front-end interfaces will be connected via Ethernet to control console workstations and central C-AD servers.
- 1.3 Diagnostics
  - Faraday cups, current transformers, and profile monitors in LEBT, MEBT, and HEBT
- 1.4 Magnet Systems
  - EBIS warm solenoids, HEBT dipoles, MEBT and HEBT quads
- 1.5 Power supplies
  - All power supplies for the EBIS, external ion sources, and transport lines.
- 1.6 RF Systems
  - High and low level rf systems for operation of the RFQ, Linac, and bunchers

WBS Descriptions (cont.)

ELECTRON BEAM ION SOURCE

- 1.7 Vacuum Systems
  - Vacuum components for EBIS, external ion sources, all transport lines, and accelerators. Excludes specialized vacuum chambers on EBIS and LEBT, which are in Structural Components.
- 1.8 Cooling Systems
  - All cooling water systems for EBIS, RFQ, Linac, transport line magnets, and power supplies.
- 1.9 Facility Modifications
  - Relocation of existing power to disconnect switches and then all equipment, plus a port allowing the HEBT line to pass through earth shielding between the Linac and Booster.
- 1.10 Installation
  - Installation in the final location of all structural components, control systems, diagnostic and instrumentation systems, magnets, power supplies, RF systems, vacuum systems, and cooling systems.
- 1.11 Project Services
  - Level of effort tasks associated with the daily management, oversight, and statusing of the project.

Preliminary Cost Estimate

WBS		Description	AY K$
1.1	**Structural Components**		3,275
	1.1.1	EBIS Hardware	1,300
	1.1.2	LEBT and External Ion Injection	500
	1.1.3	RF Structures	1,475
1.2	**Controls Systems**		600
1.3	**Diagnostics/Instrumentation**		675
1.4	**Magnet Systems**		600
1.5	**Power Supply Systems**		1,975
1.6	**RF Systems**		2,325
1.7	**Vacuum Systems**		1,450
1.8	**Cooling Systems**		300
1.9	**Facility Modifications**		700
1.10	**Installation**		1,900
	1.10.1	Structural Components	400
	1.10.2	Control Systems	50
	1.10.3	Diagnostics/Instrumentation	200
	1.10.4	Magnet Systems	25
	1.10.5	Power Supply Systems	500
	1.10.6	RF Systems	25
	1.10.7	Vacuum Systems	300
	1.10.8	Cooling Systems	400
1.11	**Project Services**		625
1.12	**Commissioning**		
		currently included in above WBSs	
1.13	**R&D**		1,200
		Conceptual Design Report	200
		Development	1,000
		Subtotal EBIS MIE	15,625
		Contingency	3,675
		Estimated Total Project Cost	19,300

Preliminary Cost Estimate

ELECTRON BEAM ION SOURCE

WBS		Burdened, AY$ Mat'l	Labor	Cont $	Total
1.1	Structural component	2015	1260	890	4165
1.2	Controls	435	165	135	735
1.3	Diagnostics	380	295	135	810
1.4	Magnets	350	250	130	730
1.5	PS's	1665	310	500	2475
1.6	RF systems	1670	655	630	2955
1.7	Vacuum	940	510	290	1740
1.8	Cooling	240	60	60	360
1.9	Facility mods	475	225	180	880
1.10	Installation	180	1720	400	2300
1.11	Project Services	0	625	125	750
	R&D	415	585	200	1200
	CDR		200		200
	Totals:	8765	6860	3675	**19300**

DOE and NASA funding profiles

ELECTRON BEAM ION SOURCE

Total
(19.3 M$)

	FY 05	FY 06	FY 07	FY 08	Total
R&D	0.5	0.7	-	-	1.2
CDR	0.2	-	-	-	0.2
PED/EDIA	-	2.0	0.5	-	2.5
Cons	0.5	0.4	6.0	8.2	15.1
Pre-Ops	-	-	-	0.3	0.3
TEC	0.5	2.4	6.5	8.2	17.6
TPC	1.2	3.1	6.5	8.5	19.3

DOE Contribution
(14.8 M$)

	FY 05	FY 06	FY 07	FY 08	Total
R&D	0.5	0.1	-	-	0.6
CDR	0.2	-	-	-	0.2
PED/EDIA	-	2.0	0.5	-	2.5
Cons	-	-	4.5	6.7	11.2
Pre-Ops	-	-	-	0.3	0.3
TEC	-	2.0	5.0	6.7	13.7
TPC	0.7	2.1	5.0	7.0	14.8

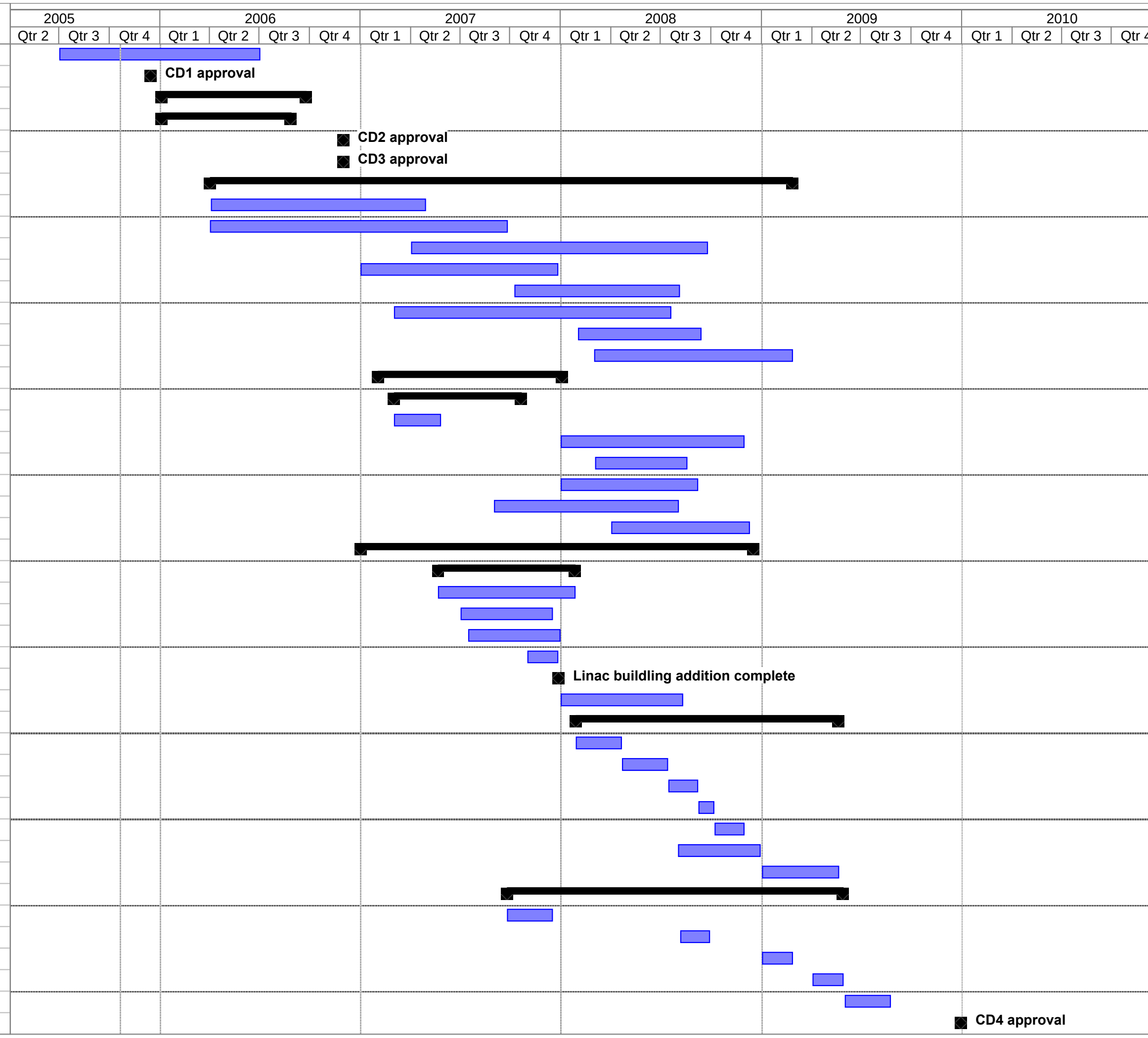
NASA Contribution
(4.5 M$)

	FY 05	FY 06	FY 07	FY 08	Total
R&D		0.6			0.6
CDR					-
PED/EDIA					-
Cons	0.5	0.4	1.5	1.5	3.9
Pre-Ops					-
TEC	0.5	0.4	1.5	1.5	3.9
TPC	0.5	1.0	1.5	1.5	4.5

Schedule (high level, early finish)

ELECTRON BEAM ION SOURCE

ID		Task Name
1		**R&D**
2		**CD1 approval**
3		**Engineering & Design**
8		**Specifications**
12		**CD2 approval**
13		**CD3 approval**
14		**Procurement**
15		Superconducting solenoid
16		RFQ
17		Linac, Bunchers
18		HEBT Dipole magnet
19		Electron collector ps
20		RF PS (1st)
21		RF PS (2nd)
22		HEBT Dipole ps
23		**Other EBIS procurements**
27		**LEBT procurements**
30		RFQ vacuum
31		Controls (excluding EBIS)
32		Vacuum (MEBT-to-HEBT)
33		Power supplies (MEBT-HEBT)
34		Diagnostics
35		RF coax, LLRF, circulators
36		**Manufacturing**
44		**Pre-assembly**
45		EBIS
46		LEBT
47		Power modifications
48		Beam access port
49		Linac buildling addition complete
50		Cooling systems
51		**Installation**
52		EBIS, platform
53		LEBT
54		RFQ
55		MEBT
56		Linac
57		HEBT (Booster side)
58		HEBT (Linac side)
59		**Testing**
60		RFQ with Test EBIS
61		RHIC EBIS
62		EBIS & RFQ
63		EBIS/RFQ/Linac
64		**Commissioning**
65		**CD4 approval**



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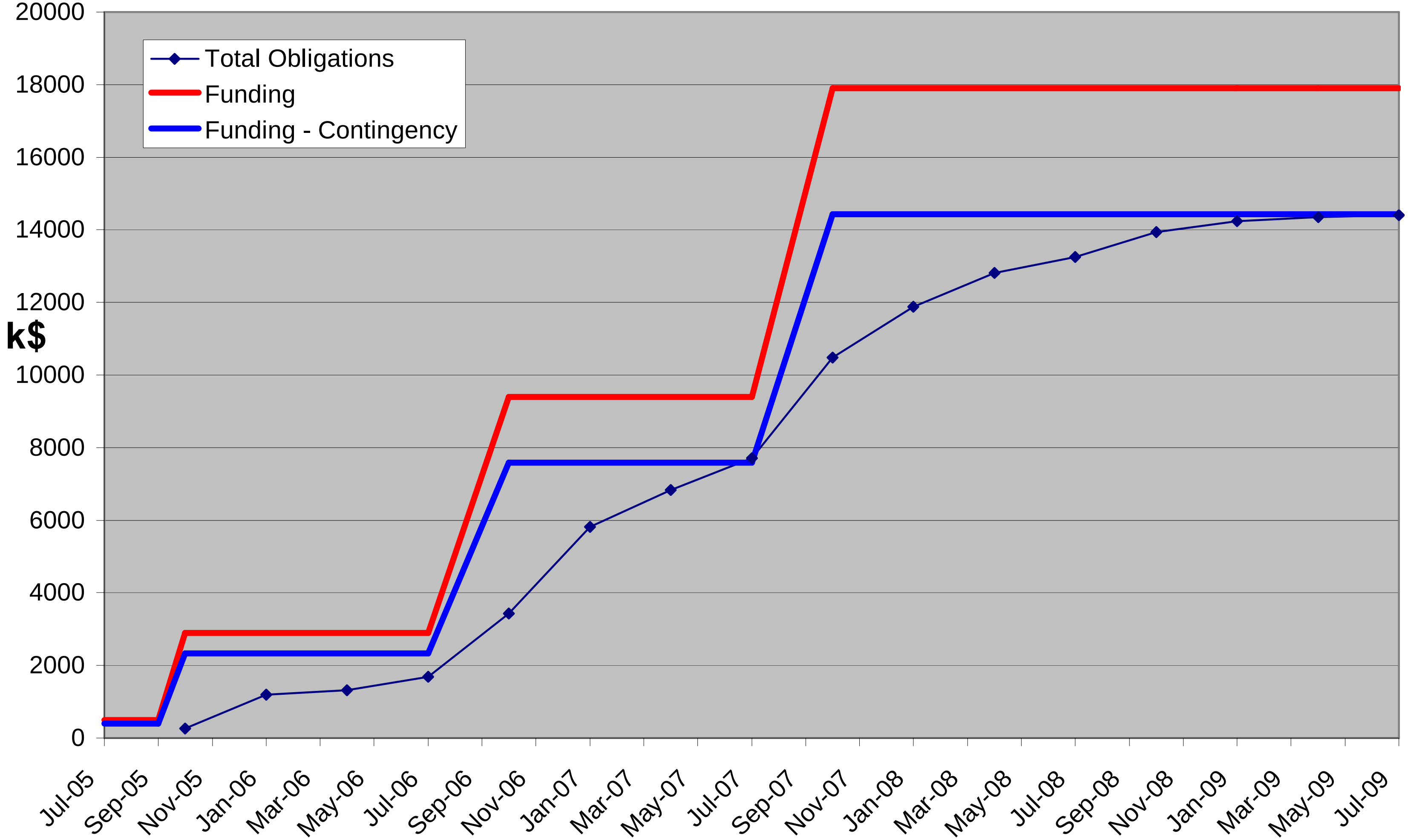
Funding/Obligation Profile (preliminary)



Obligations from MS project, excluding 1.4 M$ for R&D and CDR prep.

Critical Path (preliminary)

The procurement and delivery of the structural components drive installation and testing. Phased funding to the vendors will be needed.

- Major procurements
  - RFQ delivery by 7/07 (18 mo. lead)
  - Linac delivery by 7/08 (18 mo. lead)
  - EBIS SC solenoid delivery by 2/07 (14 mo. lead)
  - HEBT dipole delivery by 4/08 (12 mo. lead)

  Procurements are staged to fit the present funding profile

- Beneficial occupancy of the extension, and beam port completed, by 10/07

Functional Requirements

ELECTRON BEAM ION SOURCE

Species	d to U (assuming appropriate external ion injection)
Intensity in desired charge state (EBIS beams)	up to 1.1 x 10^{11} charges/pulse, depending on species
Charge-to-mass ratio, Q/m	≥ 0.16, depending on ion species
Repetition rate	5 Hz
Pulse width	10 – 40 μs
Switching time between species	1 second
Output energy	2 MeV/amu

Deliverables

As part of the project, the following items will be fabricated or procured:

a) Electron Beam Ion Source
b) RFQ accelerator
c) Linear Accelerator
d) Beam transport lines for matching the beam from EBIS to RFQ,
RFQ to Linac,
and Linac to Booster
e) Power supplies, vacuum systems, diagnostics and controls
required for the operation of all elements

CD4 requirements will be met when:

- All items required to meet the functional requirements listed in the previous table are in place and subsystems are tested.
- The EBIS-based pre-injector is commissioned with Au and Fe ion beams and has produced, at Booster input, 3 x 10^8 Au^{32+} ions/pulse and 4 x 10^8 Fe^{20+} ions/pulse (> 10% of design parameters).
- Switching between species has been demonstrated.

Summary

- The EBIS preinjector is based on a modern technology, which will be simpler to operate and easier to maintain than the Tandems and will have the potential for future performance improvements.
- It will provide a robust and stable preinjector, which is important for the successful operation of the injectors.
- The RHIC EBIS design has been verified by the present EBIS operating at BNL (next talk).
- No significant improvement in EBIS performance is required, other than the straightforward scaling of ion output with an increase in trap length. The RFQ and linac are very similar to devices already operating at other labs.
- With joint funding from DOE and NASA, some long-lead procurements should begin in CY 2005.
- Our present schedule has commissioning of the full preinjector in 2009